

We claim:

1. A free space optical switch having an input optical signal channel and an output optical signal channel comprising:
 - a first switching mirror for receiving the input optical signal incident thereon at an incidence angle with respect thereto and for reflecting the input optical signal at a first reflection angle;
 - a second switching mirror for receiving the input optical signal from the first switching mirror at an incident angle corresponding to the first reflected angle and for reflecting the input optical signal at a second reflection angle for directing the input optical signal to the output optical channel; and,
 - wherein said first and said second switching mirrors each comprise a movable member supported for movement with respect to a corresponding fixed member for controllably selecting said first and said second reflection angles, each said movable member including a magnetic element fixedly attached thereto and each said fixed member including a magnetically permeable stator element fixedly attached thereto and positioned within a magnetic flux field of said magnetic element with an air gap formed between the magnetic element and the stator element and wherein a magnetic traction force acts across the air gap for urging the moving member toward the fixed member.
2. A free space optical switch according to claim 1 further comprising at least one stator current coil wound onto a portion of each of the stator elements for inducing an electromagnetic force within the stator elements in response to currents passing through the at least one stator coil, said electromagnetic forces acting on the magnetic elements.
3. A free space optical switch according to claim 2 further comprising a current driving circuit connected with each of the at least one stator current coils for providing a current to each of the stator coils for generating the electromagnetic force in the stator elements with a direction and a magnitude for one of, increasing and decreasing a magnitude of said tractive force.

4. An apparatus according to claim 3 wherein the current driving circuit further provides a current to each of the stator coils for generating the electromagnetic force in the stator elements with a direction and a magnitude for rotating the switching mirror about at least one rotational axis.
5. The apparatus of claim 1 wherein the movable element further comprises:
 - an outer bearing surface and the fixed member further comprises an inner bearing seat for receiving the outer bearing surface therein such that a coefficient of friction between the bearing surface and the bearing seat provides a friction torque when combined with a clamping force; and,
 - wherein said clamping force is provided by the magnetic tractive force which is selected to have sufficient magnitude for holding the movable member in a stationary orientation with respect to the fixed member during normal operation.
6. The apparatus of claim 5 wherein said outer bearing surface comprises a substantially spherical surface and wherein said inner bearing seat comprises a substantially spherical bearing raceway.
7. The apparatus of claim 5 wherein said outer bearing surface comprises a substantially cylindrical surface and wherein said inner bearing seat comprises a substantially cylindrical bearing raceway
8. An apparatus according to claim 1 wherein the movable member includes a first side having the switchable mirror fixedly attached thereto and a second side, the apparatus further comprising:
 - an outer spherical bearing surface on said second side;
 - an inner spherical bearing raceway formed in the fixed member for receiving the outer spherical bearing surface therein such that the movable member is supported for rotation with respect to the fixed member; and,

- wherein the stator element is configured to provide mutually perpendicular electromagnetic forces in response to drive currents in the at least one stator coil, said mutually perpendicular electromagnetic forces providing mutually perpendicular rotations of the movable member for orienting the switchable mirrors.

9. An apparatus according to claim 1 further comprising; means for determining an actual orientation of said first and said second switchable mirrors with respect to a first and a second mirror reference orientation.

10. An apparatus according to claim 4, further comprising; means for providing an electrical signal representative of an orientation of each of the switchable mirrors with respect to a reference orientation, said electrical signal being communicated to the current driver circuit for determining the direction and the magnitude of a driver current needed to rotate the switching mirrors to a desired orientation.

11. An apparatus according to claim 2, further comprising:

- a plurality of input optical signal channels and a plurality output optical signal channels;
- a plurality of first switching mirrors corresponding to the plurality of input optical channels;
- a plurality of second switchable mirrors corresponding to the plurality of output optical channels;
- a master controller for controlling the orientation of each of the switchable mirrors for directing any one of the plurality of input optical signal channel signals to any one of the plurality of output optical channels by adjusting the first and the second reflection angles; and,
- a switch logic CPU for providing switching commands to the master controller for directing the master controller according to a desired interconnection configuration.

12. An apparatus according to claim 11, further comprising:

- two servo controlled current drivers corresponding to each of the plurality of first and second switchable mirrors for providing;
- a first drive current for rotating the switchable mirrors about a first rotation axis;
- a second drive current for rotating the switchable mirrors about a second rotation axis;
- and,
- wherein said first and said second rotation axes are substantially mutually perpendicular axes.

13. An apparatus according to claim 11, further comprising:

- a first servo controlled current driver for providing a first drive current for rotating at least one of the switchable mirrors about a first rotation axis;
- a second servo controlled current driver for providing a second drive current for rotating at least one of the switchable mirrors about a second rotation axis, said first and said second rotation axes comprising substantially mutually perpendicular axes;
- and,
- an interconnecting circuit provided between the first servo controlled current driver and a plurality of switchable mirrors for rotating each of the plurality of switchable mirrors about the first rotation axis;
- an interconnecting circuit provided between the second servo controlled current driver and a plurality of switchable mirrors for rotating each of the plurality of switchable mirrors about the second rotation axis; and,
- wherein the interconnecting circuits are switchable for switching driver currents to one of the switchable mirrors at one time.

14. An apparatus according to claim 11 wherein:

- each of said plurality of first switching mirrors corresponding to the plurality of input optical channels is supported in a first unitary fixed member having a plurality of bearing seats formed therein for receiving the corresponding plurality of movable elements therein;

- each of said plurality of second switchable mirrors corresponding to the plurality of output optical channels is supported in a second unitary fixed member having a plurality of bearing seats formed therein for receiving the corresponding plurality of movable elements therein; and,
- a plurality of stator elements are fixedly attached to the first and second unitary fixed members with one stator element associated with each of the plurality of bearing seats.

15. An apparatus according to claim 14 wherein the unitary fixed element further comprises a back plane having a plurality of conductive electrical conduits formed therewith for communicating electrical signals to and from each stator element associated with each movable element.

16. An apparatus according to claim 11 further comprising:

- a detector element associated with each of said first and said second switchable mirrors for providing an electrical signal corresponding an actual orientation of the switchable mirror with respect to a reference orientation thereof; and,
- wherein each of the detector elements is in communication with a servo current driver associated with a corresponding first or second switchable mirror.

17. A method for switching an input optical signal received from an input optical signal channel to a desired one of a plurality of output optical signal channels comprising the steps of:

- providing a first switching mirror associated with the input optical channel and a plurality of second switchable mirrors associated with each of a plurality of output optical signal channels, each switchable mirror comprising a movable member supported for movement by a fixed member;
- directing the input optical signal at the movable member of the first switching mirror at an incident angle with respect thereto;

- orienting the movable member of the first switching mirror to reflect the input optical signal toward the output mirror associated with the desired one of the plurality of output optical signal channels;
- orienting the movable member of the second switching mirror associated with the desired one of the plurality of output optical signal channels to reflect the input optical signal received from the first switching mirror to exit through the desired output optical signal channel;
- providing a magnetic element fixedly attached to the movable member of the first and each of the plurality of second switching mirrors;
- providing a magnetically permeable stator fixedly attached to the fixed member of the first switchable mirror and to each of the plurality of second switching mirrors, said magnetically permeable stators and said magnetic elements generating a magnetic traction force there between for substantially holding the movable element of each of the switchable mirrors in a stationary position during periods of no switching.

18. The method according to claim 17 further comprising the steps of:

- winding a current coil around a portion of each of the stator elements; and,
- driving a current through the current coil for inducing an electromagnetic force in the stator elements for acting on the magnetic elements to one of increase and decrease the magnetic traction force.

19. The method according to claim 18 further comprising the step of driving a current through the current coils for inducing the electromagnetic force in the stator elements for acting on the magnetic elements to rotate the movable members about at least one rotation axis.

20. The method according to claim 17, further comprising the steps of:

- determining an actual orientation of each of the movable members with respect to a reference orientation; and,
- generating an electrical signal representative of the actual orientation.

21. A method according to claim 20, further comprising the step of using the electrical signal representative of the actual orientation of each of the movable members for determining a direction and a magnitude for rotating each of the movable members to achieve an orientation for directing the input optical signal to the desired output optical signal channel.

22 A method according to claim 21, further comprising the steps of:

- providing a first electrode plate attached to and movable with the movable member;
- providing a second electrode plate that is stationary with respect to the first electrode plate, said second electrode plate having at least two segments that are electrically isolated from each other and from the first electrode plate by a capacitor air gap;
- applying a varying voltage to the first electrode plate;
- measuring a capacitance in each of the at least two segments; and,
- using a difference in the measured capacitances to estimate an actual position of the movable member.

23. A method according to claim 21, further comprising the steps of:

- providing a reflective surface attached to and movable with the movable member;
- providing an optical signal incident on the reflective surface at a fixed incident angle;
- positioning an optical signal detector to receive the optical signal after reflection from the reflective surface as the reflective surface moves with the movable member, said optical detector having at least two segments that are electrically isolated from each other;
- measuring an electrical signal generated by each of the segments of the optical signal detector in response illumination of the optical detector by the optical signal after reflection from the reflective surface; and,
- using a difference in the measured electrical signals to estimate an actual position of the movable member.

24. A method for controlling an optical beam with a movable optical element comprising the steps of:

- providing an control element comprising a movable member supported for movement by a fixed member, said movable member including an optical element fixedly attached thereto;
- providing a magnetic element fixedly attached to the movable member; and,
- providing a magnetically permeable stator element fixedly attached to the fixed member, said stator element and said magnetic element mutually generating a magnetic traction force there between for substantially holding the movable member in a stationary position during periods when the movable member is not moving.

25. The method according to claim 24 further comprising the steps of:

- winding a current coil around a portion of the stator element; and,
- driving a current through the current coil for inducing an electromagnetic force in the stator element for acting on the magnetic element to one of increase and decrease the magnetic traction force.

26. The method according to claim 25 further comprising the step of driving a current through the current coil for inducing the electromagnetic force in the stator element to cause the magnetic element to rotate the movable element about at least one rotation axis.

27. The method according to claim 26, further comprising the steps of:

- determining an actual orientation of each of the movable members with respect to a reference orientation; and,
- generating an electrical signal representative of each of the actual orientations.

28. A method according to claim 27, further comprising the step of using the electrical signal representative of the actual orientation for determining a direction and a magnitude of a drive current required to rotate the movable member to a desired orientation.

29. An apparatus for controlling an optical beam comprising:

- a movable member supported for movement by a fixed member, said movable member including an optical element fixedly attached thereto;
- a magnetic element fixedly attached to the movable member; and,
- a magnetically permeable stator element fixedly attached to the fixed member, said stator element and said magnetic element mutually generating a magnetic traction force there between for substantially holding the movable member in a stationary position during periods when the movable member is not moving.

30. The apparatus according to claim 29 further comprising:

- a current coil wound around a portion of the stator element; and,
- a current driver for providing a current in the current coil thereby inducing an electromagnetic force in the stator element, said electromagnetic force acting on the magnetic element to one of increase and decrease the magnetic traction force.

31. The apparatus according to claim 30 wherein the current driver is configured to provide a current in the current coil for inducing the electromagnetic force in the stator element to cause the magnetic element to rotate the movable element about at least one rotation axis.